A Contribution to the Role of the Wireless Sensors in the IoT Era

Muhammed Abaid Mahdi, Saad Talib Hasson

College of Information Technology, University of Babylon

mohamedubed@yahoo.com

***Abstract*—Wireless sensor networks (WSNs), which are associated with the Internet of Things (IoT), represent useful networks in assisting monitoring, tracking and sensing different environmental activities. Sensors play an essential role in designing and applying any WSN. Due to the vast advances in communication and networking technology, there are needs to develop, build and apply various smart or intelligent (unmanned) service networks. The concept of IoT refers to equipping real objects with communication and computing facilities that enables collaboration with each other in real life applications. IoT inclines toward the process of controlling, communicating, cost-saving and automation. At present, this era will be the IoT era due to its numerous vital applications. This paper aims to review the status of the IoT and its applications' requirements. It also aims to survey the role of the sensors in this context. The paper provides a good overview of the important characteristics and applications of the WSNs and IoT. This work represents a suitable guide for researchers who are interested in such fields.**

***Index Terms*—Applications; Challenges; Characteristics; IoT; Metrics; Sensors; WSN.**

I. INTRODUCTION

Physical or environmental conditions can cooperatively be monitored or sensed using wireless sensors. In this context, sensors have a big contribution in those applications [1]. Environmental monitoring, building controller, transportation management and healthcare services are the main applications of IoT. The low cost of sensors has encouraged researchers to deploy them in an ad hoc manner for sensing or controlling procedures. However, these sensors have severely suffered from several constraints such as energy, storage and computational capabilities. Therefore, the life-time of sensors should be taken into account to maximize the life-time of the whole network. To achieve this goal, selecting the appropriate sensors has a significant impact on minimizing the energy consumption and maximizing the range of the coverage [1]. Depending on the application for which the sensors are used, there are several strategies that have been suggested to overcome those constraints.

II. APPLICATIONS OF THE IOT

According to [2], there are five categories of sensors. They are designed for underground applications, underwater applications, terrestrial applications, multimedia applications and mobile applications. Although terrestrial sensors are cheaper than the others, they still have limited battery capacity. Sometimes, burying sensors underground is required to monitor specific conditions in applications such as the agricultural applications or mining applications. Therefore, these types of sensor could be expensive due to the nature of those applications. On the other hand, acoustic waves are needed for communication process in underwater applications. Because of the hostile environment of the ocean, sensors are non-reachable. Therefore, the energy consumption of the sensors should be carefully considered [3,4].

Tracking objects or events in multimedia applications require microphones and cameras. Moreover, the high data rate is essential to send and receive videos, audios or images.

Lastly, portable sensors in mobile applications such as military field are used. Here, attention to communication range should be paid. Sensors can move and change their positions in the network. Dynamic mechanisms are needed to send data and to organize the network [4].

Users may interact with sensors that are embedded in surrounding environments such as buildings or vehicles [5]. According to the previous discussion, applications of IoT can be broken into several types based on their missions and environments [4]. As long as the geographic area of application is increasing, the need for a specific sensor is needed [6, 7]. So, classification of Applications can be dividing into two types according to the geographical area. Figure 1 illustrates the classification of IoT's applications.

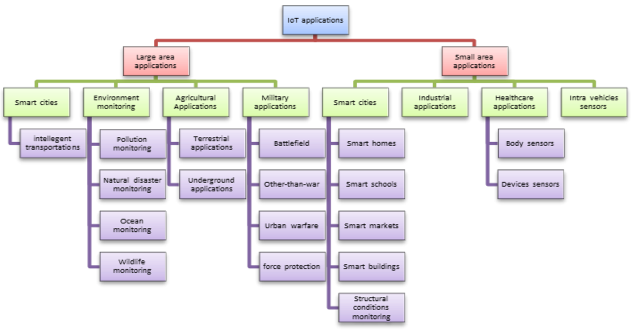

Figure 1: Applications of IoT

A. *Large Area Applications*

Smart Cities: Nowadays Smart Cities have increasingly been brought to light. Intelligent objects that have CPU and transceiver device to communicate with each other are the main components of that city [8]. These intelligent objects could provide a safe and smart environment. This scenario is also called Internet of Things (IoT). Internet of Vehicles (IoV) is a subclass of IoT by which transportation system will be more intelligent. There are three communication scenarios in IoV. These are Vehicles-to-vehicles, vehicles to roadsides and roadsides to roadsides [9]. VANETs are used in numerous applications such as automobiles speed monitoring, traffic jam avoidance, best route finding, and outside to vehicles communication. IoVs consist of a large number of vehicles and some roadside stations that can be deployed in an ad hoc or cellular mode for remote operations. Vehicles are severely constrained in terms of mobility, direction and unstable topology.

Smart Environmental: There is a long history in environmental monitoring. Pollution monitoring is another large area of application. Due to the importance of having clean environments with as little pollution as possible, many papers have been suggested exploiting WSNs in this event [10]. Fire detection systems have been investigated when outdoor sensors are deployed in the large area [11]. The main environmental applications are flooding detection volcano eruption, earthquake and chemical hazardous detection. Moreover, underwater applications such as controlling water pollution and monitoring sea animals [12]. Furthermore, sensors have been installed close to animals' bodies to monitor conditions related to rear conditions, produced gases and animal temperature.

Smart Agricultural: Wireless sensors have a significant impact on the agricultural applications [13]. Indeed, monitoring soil and crops have taken a big attention from scientists ranging from agricultural irrigation to fertilizer management. Classical ways of measuring agricultural parameters could be difficult, especially in the large area fields [14]. Therefore, sensors are a suitable solution to collect data [15, 16]. In fact, WSN provides a better way than the traditional ways that need effort and attendance [17]. Thus, low cost of intelligent sensors supplied with small batteries and wireless communication capabilities have been presented. There are two main categories of sensors for agricultural applications. These are wireless terrestrial sensors and wireless underground sensors [18-20].

Military Applications: An extending area of interest from just information collection to tracking or surveillance is an essential characteristic of military applications [21]. According to [22], authors classify military applications into four classes. These are battlefield, force protection, urban warfare and other-than-war.

B. Small Area Applications

Structural Conditions Monitoring: Buildings and bridges need to be measured for mechanical stress, especially after natural disasters such as earthquakes [23].

Industrial Applications: Controlling industrial devices are the main significant aspect that highlights the automata industries. In addition, manufacture monitoring is the important process in industrial applications [23].

Healthcare Applications: Body sensors that can monitor health conditions like respiratory, blood pressure, blood flow, ECG, and oxygen. New drugs could be developed basing on the data that has been collected by the intelligent sensors [24].

Intra-vehicle Applications: Smart vehicles consist of many sensors deployed in those vehicles. These sensors give a good view about the status of vehicles. For instance, tire pressure, engine status and speed are the most needed parameters in some applications. Moreover, container surveillance in trains or ships is another example of intra-vehicles sensors [25]. Such applications do not need energy awareness. However, the consumption of energy is still taken in account to reduce CO2 in the environment. Indeed, most communication processes might have a little contribution to the emission of CO2 [26].

III. NECESSARY CRITERIA FOR DESIGNING WSN

Several factors should be addressed when WSNs are designed. These factors have been regarded as a guideline to build algorithms or protocols for WSNs [27]. Furthermore, these factors can be considered comparative criteria to evaluate different schemes. Application requirements have to be addressed as an initial step to design WSN for that application. When those requirements are highlighted, suitable technologies can be selected to meet these requirements.

C. Important Requirements for Applications

Before designing WSN, attention has to be paid to several requirements. These requirements are related to the achievement of objectives and functions WSN is designed. The most important requirements will be discussed in the next sections [28-31].

Quality of Service (QoS): QoS is related to the reliability and priority mechanisms in WSNs. Thus, sensors can perform some emergent applications, such as object tracking or fire detection. In such applications QoS should be used to enhance the security and reliability of WSN [28]. As a result, three main limitations should be addressed when new protocols are designed for critical applications. These are data redundancy, collision and resource constraints.

Fault Tolerance: Due to hostile environment, sensors might fail [4]; however, WSN should not be influenced by this failure. In this context, each algorithm or protocol designed for WSNs should have fault tolerance. A different fault tolerance level is associated with each application. In home applications, for example, when operating as humidity or temperature monitoring, a high fault tolerance is not needed since sensors are not easily damaged. However, outdoor environments are regarded in hard environment. Thus, a high fault tolerance is required to avoid failure possibilities [4].

Time of Data Delivery: Delay is bounded on delivering data in applications that require real time delivery. Service latency should be bounded in time critical applications [29]. In healthcare, for example, if doctors do not receive alerts on time, the lives of patients might be in danger [30]. So, elapsed time between the source and attention should be taken into consideration when designing protocols or algorithms. Depending mainly on the nature of application, it is essential to respect a minimum allowed delay. Scalability: Since hundreds or thousands of sensors are deployed based on the application, the designer should be careful when dealing with the possibility of extending the network [1]. However, this high density of sensors has to be exploited to cover as large area as possible.

Energy Consumption: Replaceable or recharging batteries, in some applications, may be impossible or difficult. Therefore, battery lifetime affects strongly the lifetime node. As a result, the lifetime of the whole network will be negatively influenced. In the worst case, when nodes may be routers, the entire network will be degraded by this failure. Sensing processing, transmitting and receiving are the main tasks through which sensors consume energy [31]. Moreover, noise can increase consumption of power due to retransmissions. In [32], data compression techniques dedicated to WSNs are investigated to reduce the power consumption. Authors have concluded that data communication consumes more than data processing. Many communication processes are done in WSNs including transmission, reception, frequency synthesizers, voltage control, etc. and all of those processes consume the amount of sensors' power. For these reasons, energy consumption has been widely discussed in many papers [31].

Gathering Data: According to the way by which data will be gathered, WSN applications may be either Event Detection (ED) or Spatial Process Estimation (SPE) [29]. In ED, a specific event, such as fire, needs to be detected by deploying sensors. In contrast, SPE is involved to predict a physical condition, such as ground temperature in a volcano or atmospheric pressure. However, some of the environmental applications may belong to both classes.

Homogeneous vs. Heterogeneous: WSNs are called homogeneous networks when all sensors are the same. On the other hand, heterogeneous networks consist of different types of sensors. Although homogenous networks are easy to manage, heterogeneous networks may provide a suitable solution due to having different models of energy [33]. Sometimes, assigning a heavy task for certain nodes is required because they have more energy than the others. Indeed, cluster heads work as a router in a cluster of nodes. Hence, it is practical to have more energy to transceiver the data than the other nodes [34]. Therefore, heterogeneous networks might maximize the lifetime of the network. Nonetheless, homogeneous networks are easily deployed. Moreover, switching cluster heads can be done to avoid nodes' death.

Communication Architecture: There are two main tasks of sensors. These tasks are either sensing or routing data to the sink node. Sink node and all nodes in the network pass through a layered communication process. This process is called communication architecture or a protocol stack [31].

D. Operating Systems of Sensors

While sensors are intelligent devices, they have Operating System to manage computation and memory. There are several types of OSs, and they are different from each other according to some considerations. These considerations are architecture, programming model, scheduling, memory management, communication protocols and resources sharing. Architecture is related to how OS provides its services for applications. Four main architectures of OSs are available. These are monolithic, microkernel, virtual machine and layered architecture [35]. In the context of the programming model, the OS of sensor provides two programming models, which are either event-driven or multi threading programming. On the other hand, OS should schedule the tasks according to the scheduling algorithm provided by that OS. Although sensors have a small memory, OS should provide a way to manage this small memory. While sensors communicate with each other, Communication protocols should be provided by OS. Each OS provides built-in protocols for communications. Like all multiprocessing OSs, the sensor of OS is responsible for allocating resources among processes.

Several OSs have been designed for sensors [36]. Each one has specific features to carry out several tasks. The next sections will discuss the most familiar sensors of OSs.

1) *TinyOS*
   It uses monolithic architecture, event driven programming model, FIFO scheduling, static memory management, TDMA/CSMA communication protocols and event completion allocation.
2) *Contiki*
   It provides Modular architecture, multithreading model, Rime communication protocols and serial access allocation.
3) *MANTIS*
   It uses layered architecture, multithreading model, priority scheduling, first part user protocols and semaphore resources allocation.
4) *Nano-RK*
   Monolithic is used as architecture. Multithreading is used as a programming model. Priority is its scheduling algorithm. It uses static memory management. Semaphore is a source of allocation for algorithm.
5) *Lito OS*
   It provides multi tasking architecture, round robin scheduling algorithm, dynamic memory management and synchronization resource sharing.

E. Wireless Standard Technologies for Sensors

Achieving the communication requirements needs a suitable design of wireless technology. Several Radio Frequency technologies are designed for WSNs [37]. The requirements, which should be met in WSNs are coverage range, data rate, and power consumption. These parameters determine which radio frequency technology is suitable for specific application requirements. Table 1 shows the characteristics of some familiar wireless technologies [38, 39].

Hardware Platforms for Sensors: Selecting an appropriate sensor depends on the nature of the application. Many criteria have to be considered when a designer chooses a sensor. Table 2 illustrates the main features of the familiar sensors' platforms [37-40].

IV. TEST TOOLS

The most important step in WSNs design is evaluating the performance of algorithms and protocols. Evidences that claim protocols or algorithms has a good performance is needed. Since executing suggested systems is difficult in the real world, simulators and testbeds are available for this task [41]. Some the familiar simulators and testbeds will be discussed in the next sections.

Table 1
Wireless Technologies

Wireless technology	Data Rate	Range	Data type	Power consumption
Bluetooth	Low data rate 1 mbs	Short distance 10m	Images or files	Low power mode 1 weak
WiFi	54Mbs- 6 Gbs	100 m	Video, audio or files	Hours
Wibree	Very low	Short distance	Small files	Less energy consumption
ZigBee	256 Kbs	75 m	Small files	1 Year

Table 2
Types and Features of Sensors

Platform	Company	CPU	RAM	Wireless Technology
AVID Director	AVID Wireless	Imsys CJIPjava 160 MIPS" processor	8 or 16 MB	Wi-Fi, Bluetooth or ZigBee
WMSNP	Convergix	8MHz	512 bytes	9600 bps
MeshScape	Millennial	-	-	57 Kbps bitrate
SensiNet	Sensicast	-	-	91-304 m
EnRoute	Sensoria's EnRoute 500	-	-	6-24 Mbps bitrate
Tmote Sky	Moteive	MSP430F1611	10 KB RAM	250 Kbps bitrate
MICAx	Crossbow technology	Atmega 128L, 8 MHz	4KB RAM	38.4 Kbps bitrate

F. Simulations

Simulators are good alternatives to test designed WSNs. Due to difficulties, the real-world testing could be expensive or dangerous. So, most of the researchers have tested their proposed systems using those simulators. There are two main classes of simulators in WSNs. The first is the academic simulators and the second is the commercial simulators [42,43,46].

Academic simulators: Four familiar academic simulators will be discussed in the next four paragraphs [42].

1) *Ns-2 and Ns-3*
This simulator is built in C++ programming language. Ns-3 is an extension of Ns-2, in which scripts can be written in C++ or Python [43].
2) *OMNeT++*
It is also compatible with the C++ environment. A good infrastructure is provided to simulate WSNs. IEEE. 802.11, SCSL, FDDI and TCP/IP protocols are supported by OMNet++. In addition, a good scalability is also available (number of nodes).
3) *GloMoSim*
C-based simulator is designed by parallel programming. Protocols of wireless networks are supported by GLoMoSim. It is also scalable, including approximately 1000 nodes.
4) *Ptolemy*
Ptolemy is a Java-based simulator to support concurrently. Moreover, real time systems and heterogeneous systems are supported by Ptolemy. Nevertheless, scalability of Ptolemy is limited to a few nodes.

Commercial simulators:-

1) *QualNet*
The real-time networks are supported by QualNet simulator. It provides extension and interface to other simulators [42].
2) *OPNET*
This simulator is regarded as a hierarchical simulator. In fact, it provides a set of processes for each node like Finite State Machine (FSM). Three links types are provided by OPNET: bus, wireless, and point-to-point [43].

G. Testbeds

Due to unrealistic assumptions, simulators might produce inaccurate results. On the other side, the real-world test is difficult and dangerous. This big gap between simulators and real-world tests needs to be bridged. For that purpose, testbeds are available to trade off between realistic and cost. Selecting a suitable testbed depends on several factors such as experiment analysis, experiment reproducibility and experiment control. Furthermore, some characteristics such as user interfaces operating systems, the range of environments and platforms provided by the testbed should be considered when selecting it. Chronical list is mentioned in the next paragraphs [44-47].

1) *Emulab (2002)*
A wide range of environments is provided to test WSNs. It supports a strong user interface for interaction with the tested systems [44].
2) *GNOMES (2003)*
It is specifically built for heterogeneous WSNs. It uses different architectures with low-cost hardware to achieve the design trade-offs [45].
3) *SensorScope (2004)*
The clear characteristic of this testbed is sensing stations with solar-powered. Researchers are allowed to easily add or/and delete sensing stations. In addition, a resetting facility is available to relocate the sensor nodes geographically and reset them [46].
4) *ORBIT (2005)*
Reproducibility can be achieved to reproduce the experiments. The real-world setting is provided to evaluate protocols and applications [47].
5) *Motelab (2005)*
190 TMote sensor nodes can be deployed. It supports TinyOS operating system. A good interface is offered to interact with sensor nodes. NesC is a programming language of Motelab [46].
6) *SignetLab (2006)*
USB data with 48 EyesIFXv2 nodes are available in this testbed. The main facilities offered by SingetLab are nodes interaction, and Programming [46].

V. CHALLENGES

The recent challenges in WSNs can be broken into five main directions. These directions require researchers' attention. Although several papers have discussed those issues, there is still a need to address them in more detail [48-51].

A. Security

Security is the main issue in WSNs. This issue can be viewed in three views, namely secure data aggregation mechanisms, secure routing protocols, and intrusion detection [48].

B. Mobility

Sometimes, it is required that nodes should travel through the network. As a result, some issues may appear. In fact, connectivity problem, in this context, have to be addressed. Moreover, leaving and joining of mobile nodes need to be taken into account. On the other hand, deployment of mobile nodes is another issue that should be considered [49].

C. Energy Efficiency

Sensors are intelligent devices that have the capability to sense, deliver and receive data. All these operations consume energy. However, communication processes drain the most energy of sensors [6, 7]. So, dealing carefully with their energy is a significant consideration that has to be taken into account. Therefore, energy efficient communication is required to prolong the lives of sensors and eventually to maximize the lifetime of the entire network.

D. Localization

Localization in WSN plays a substantial role to locate the position of nodes in WSNs. Considering its high cost, the use of GPS to locate positions of nodes is not practical. For this reason, non-GPS localization mechanisms are needed [44].

E. Real Time Applications

The most emergent applications should achieve real time requirements. Quality of Service QoS, reliability and delay of delivery are the main requirements of real time applications. So, this direction needs to be considered in future works [51].

VI. METRICS FOR EVALUATING IOT APPLICATIONS

A. Functionality

There are three factors for functionality. Suitability refers to how much the functionality of IoT application meets the user's needs. For example, it measures the occurrence of undesired operation during the test of the IoT application. Accuracy means the instructions of users are correctly executed. Security is another factor to measure the functionality. It means the possibility to prevent unauthorized persons to access data [52].

B. Reliability

The main factors of reliability are fault tolerance and recoverability. The former means the ability for dealing with the fault of the system, whereas the latter means how effectively the system will be covered when it fails [53].

C. Efficiency

Time of processing and resources utilization should be efficiently considered. On the other hand, portability of system is also an important factor of the efficiency of the system. It means the environment of the system can flexibly be changed [52].

VII. CONCLUSION

Smart Cities have increasingly been brought to light. Intelligent objects that have CPU and transceiver device to communicate with each other are the main components of Internet of Things (IoT). As wireless sensors are cooperative devices used to sense some conditions, they have a positive effect on IoT. Intelligent networks, which are made of sensors, intelligently deal with environmental conditions. Sensors are considered as a base stone to such intelligent networks. This paper provides a good description of the most applications and structure of IoT. Taxonomy of IoT's applications is presented depending on geographical area. Moreover, a good overview of the types of sensors and research tools are investigated. Recent challenges of WSNs have been discussed. The last section discusses the metrics for evaluating IoT applications.

ACKNOWLEDGMENT

This work is supported by College of Information Technology, University of Babylon, Hillah, Iraq.

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